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The contribution of renewable resources in meeting Turkey's energy-related challenges

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ABSTRACT

The aim of this paper is to point out the importance of renewable energy as a key way for resolving the Turkey's energy-related challenges. As a consequence of economic and social development, Turkey's energy consumption has risen dramatically over the past three decades. At present, fossil fuels account for more than 90% of the total energy consumption in the country. Turkey has no large oil and natural gas reserves and it import nearly all of these fossil fuels. Turkey's current energy mix is not likely to support development of sustainable energy. The energy mix shows a relatively small contribution from renewable energy sources in the country. They have the potential to make a large contribution to Turkey's sustainable and independent energy future. In particular they can help to reach the environmental goals of Turkey and to increase the security of energy supply by reducing the dependence on imported-fuel supplies.

Contents

1. Introduction

Worldwide energy demand has been growing steadily during the past five decades, and most experts believe that this trend will continue to rise. The vast majority of the world's primary energy demand is presently being met by fossil fuels, such as oil, natural gas and coal. According to BP's Statistical Review of World Energy 2009 [1], the world's primary energy consumption in 2007 was 11,104 million tons of oil equivalents (Mtoe), of which 88% was provided by fossil fuels. World primary energy demand has risen nearly 40% since 1990, and it is expected to rise more than by 50% between now and 2030. In 2030, it is will reach 17,010 Mtoe and

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fossil fuels will continue to dominate the world energy mix, accounting for 80% of the world energy demand, according to projections of the International Energy Agency's (IEA) World Energy Outlook 2008 (WEO-2008) reference scenario [2].

The widespread and rapidly increasing use of fossil fuels within the current energy infrastructure is considered as the largest source of anthropogenic carbon dioxide (CO_2) emissions, which is largely blamed for global warming and climate change [3]. The global atmospheric concentration of CO_2 has increased from around 280 parts per million (ppm) in the pre-industrial period to 385 ppm in 2007 [4]—a 37% increase. Since the industrial revolution, CO_2 emissions from fossil fuel combustion dramatically increased from near zero to 29 gigatons (Gt) in 2006, it is expected to rise nearly 40% during the period 2006–2030, according to the Energy Information Administration's (EIA) International Energy Outlook 2009 (IEO2009) [5]. Data on world fossil fuel consumption were collected from the BP Statistical Review of World Energy 2009 [1] and the IEA WEO-2008 reference scenario [2] and fossil fuel-based CO_2 emissions data were collected from EIA-IEO 2009 [5] for the period 1990–2030. Fig. 1 shows world fossil fuel consumption and fossil fuel-based CO_2 emissions from 1990 to 2030.

The dramatic increase in the price of oil, the finite nature of fossil energy sources, increasing concerns regarding environmental impact, especially related to greenhouse gas (GHG) emissions, and health and safety considerations are forcing the search for new alternative energy sources [6]. Reducing use of fossil fuels would considerably reduce the amount of carbon dioxide produced, as well as reducing the levels of the pollutants which cause acid rain. This can be achieved by either using less energy altogether, or using alternative energy sources [7]. Environmental impact of renewable energy technologies is far less than that of fossil fuel-fired power plants. The Kyoto Protocol to the United Nations Framework Convention on Climate Change (UNFCCC), agreed to in December 1997, marks an important turning point in efforts to promote the use of renewable energy worldwide and the developed countries should decrease the net emission of CO_2 [8].

Turkey has a rapidly growing economy and, coupled with a population of over 70 million, is facing a growth in energy consumption of 8% per year. Like many other developing countries, Turkey is heavily dependent on fossil fuels to meet its energy requirements. Table 1 shows a comparison of fuel mix of total energy consumption between world and Turkey [9,10]. At the present time primary energy sources are dominated by non-renewable fossil fuels, with nearly 90% of Turkey's energy demand supplied from crude oil, natural gas, and coal. As can be seen from Table 1, current energy mix is not likely to support development of sustainable energy in Turkey. The largest share of the country's total energy consumption comes from natural gas (31.8%), followed by oil (29.9%) and coal (27.3%). Renewable energy sources (with the exception of hydro) are currently small fractions of Turkey's energy supply.

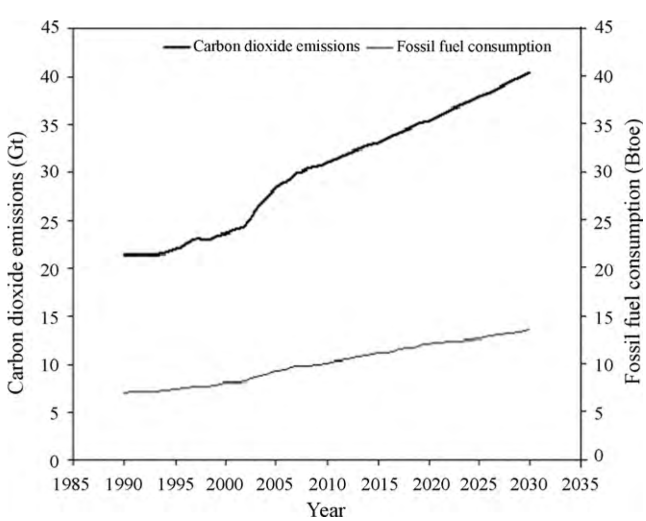


Fig. 1. World fossil fuel consumption and fossil fuel-based CO_2 emissions during the period 1990–2030.

Table 1
Comparison of fuel mix of total energy consumption between world and Turkey (%).

	Oil	Natural gas	Coal	Nuclear	Renewables (including hydro)	Reference
World (2007)	34.0	20.9	26.5	5.9	12.7	[9]
Turkey (2008)	29.9	31.8	27.3	–	11.0	[10]

In order to ensure a sustainable energy future in Turkey, various renewable energy options have been explored in numerous studies [11–21]. The aim of this paper is to point out the large potential of renewable energy in Turkey and its importance as a key way for resolving the country's energy-related challenges. This paper also discusses the present situation, future projections and developments of renewable energy and policy objectives in Turkey.

2. Turkey's renewable energy potential

Evrendilek and Ertekin [22] have conducted a detailed study on the renewable energy potential in Turkey, said that various kinds of resources like hydro, solar, wind, biomass and geothermal energy resources are available in abundance in the country. They estimated that Turkey's economically feasible renewable energy potential exceed 495 terrawatt hours per year (TWh/year) in total with the potential 196.7 TWh/year of biomass energy, 125 TWh/year of hydropower, 102.3 TWh/year of solar energy, 50 TWh/year of wind energy, and 22.4 TWh/year of geothermal energy.

3. Can renewable energy make a dent in Turkey's energy-related challenges?

Turkey's main domestic energy resources are coal (particularly lignite), hydro and biomass and it has no large oil and natural gas reserves. Turkey's potential energy reserves are given in Table 2 [23]. Given that domestic coal makes up 13.5% of Turkey's primary energy consumption, renewable energy makes up only 11%, especially hydro and biomass. 74% of the country's energy consumption derives from imported fossil fuels.

Despite limitations in domestic resource availabilities, primary and secondary energy demand in Turkey is growing very rapidly, parallel with its industrialization efforts. Projections to 2020 indicate that its energy demand will increase significantly. The Ministry of Energy and Natural Resources (MENR) [10] has planned for a very large increase in the country's energy consumption over

Table 2
Turkey's potential energy reserves (million tons).

Energy type	Total	Recoverable	Proven	Annual production
Methane from gas hydrates	14,000	–	–	–
Lignite	8080	7300	6800	55
Hard coal	1130	460	250	2
Bituminous schist	1650	1100	279	–
Asphaltite	82	45	30	–
Oil	42	–	–	2
Natural gas	9	–	–	–
Thorium	380	–	–	–
Uranium	9	–	–	–

Source: Ref. [23].

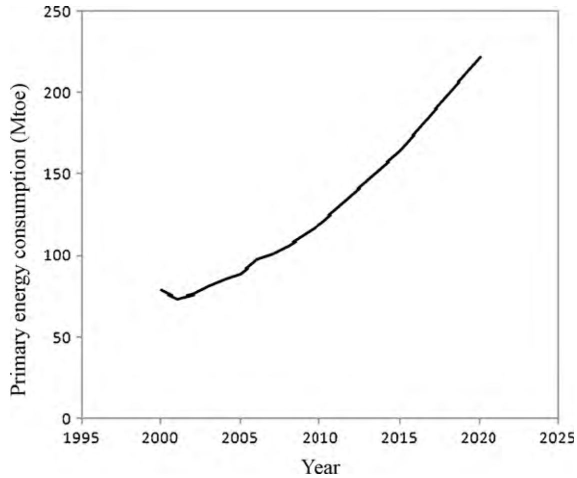


Fig. 2. Turkey's primary energy consumption during the period 2000–2020. Source: Ref. [10].

the next decade. Turkey's primary energy consumption in the long-term is projected to grow at an average rate of almost 5.9% per year, from 106.3 Mtoe in 2008 to 222.4 Mtoe in 2020 (Fig. 2). Some predict that Turkey will need up to US$128 billion in investments to fuel this growth [24].

Turkey's population of more than 70 million is growing at an annual rate of 1.04% and expected to grow to 83.4 million in 2022 [14]. If Turkey uses only traditional energy sources, it simply will not have enough energy capacity for its population. Turkey needs to rapidly switch to a new energy paradigm by radically changing its energy supply to renewable and local sources and by adopting energy efficient technologies and reductions in consumption patterns. Renewable energy sources have the potential to make a large contribution to Turkey's sustainable and independent energy future. In particular they can help to reach the environmental goals of Turkey and to increase the security of energy supply by reducing the dependence on imported-fuel supplies. Renewable energy is the key to solving Turkey's energy-related challenges. These challenges can be listed as follows:

- the heavy dependency on energy imports,
- the finite reserves of fossil fuels,
- the rapid rise in energy prices, and
- the environmental challenges.

3.1. The heavy dependency on energy imports

Turkey is currently heavily dependent on imports to meet its energy demand because of limited domestic energy resources. Currently, 97% of the country's natural gas demand, 93% of oil demand and 20% of coal demand is met by imports [25].

Natural gas consumption has been growing fast, causing a significant change in the Turkish energy market. While the share of oil in the country's energy mix has decreased slightly during the past three decades, the share of natural gas has rapidly increased. From the growth rate of natural gas consumption, since the year 1990, the country's natural gas consumption has an annual growth rate of 15% and the average annual growth is about 1.8 billion cubic meters (bcm). Globally, from 1990 to 2007, it showed an annual growth rate of 2.4%. Russia has traditionally been Turkey's largest gas supplier (63%) [26]. Dependency on a single resource harbours both an economic and a political risk in all energy types [27]. There are basically four ways to reduce our country's heavy dependence on energy imports:

1. the use of more volume of indigenous coal,
2. more efficient use of energy,
3. mobilization of nuclear energy, and
4. more effective and extend the use of renewable energy sources.

Turkey has considerably high level of renewable energy resources that can be a part of the total energy network in the country [28]. Imported fossil fuels currently play an important role in the country's electricity generation. Fig. 3 shows Turkey's electricity generation mix in 2008 and economically feasible renewable energy potential. Data on electricity generation mix were collected from the Turkish Electricity Generation Company's (EUAS) Electricity Generation Sector Report [25] and renewable energy potential data were collected from a study of Evrendilek and Ertekin [22], respectively. As can be seen in Fig. 3(A), approximately 60% of electricity generation is supplied by imported fossil fuels. Economically feasible renewable energy potential in Turkey is more than enough for total replacement of fossil fuels currently imported for the electricity generation (see Fig. 3(B)). Turkey has an economically feasible potential of 495 TWh/year, which is more than twice the current electricity generation of Turkey.

Renewables are domestic energy sources and can contribute to reduce dependence from energy imports and they permit diversification of the energy mix. Renewable energy should be taken as a key way to reduce Turkey's heavy dependence on imported energy and must be put in the first position. This will not only reduce its dependence on imports of fuel to produce energy, but will also ensure a continued local source of energy.

3.2. The finite reserves of fossil fuels

Petroleum-based fuels are obtained from limited reserves. These finite reserves are highly concentrated in certain regions of

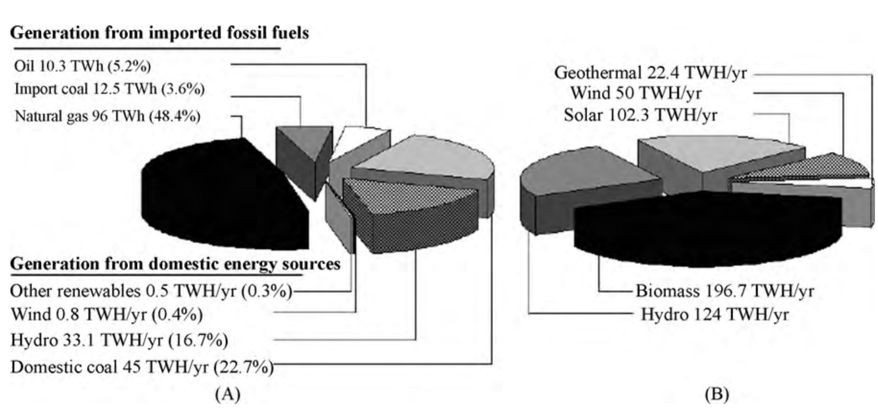


Fig. 3. (A) Turkey's electricity generation mix in 2008 and (B) Turkey's economically. feasible renewable energy potential.

Table 3
The distribution of remaining reserves of fossil fuels (at end 2008).

Country	Oil (billion tons)	Share (%)	Natural gas (billion cubic meters)	Share (%)	Coal (billion tons)	Share (%)
Middle East	102.0	59.9	75,900	41.0	–	–
Russia	10.8	6.3	43,300	23.4	157.0	19.0
Venezuela	14.3	7.9	4800	2.6	–	–
USA	3.7	2.4	6700	3.6	238.3	28.9
China	2.1	1.2	2500	1.3	114.5	13.9
Australia	–	–	2500	1.4	76.2	9.2
India	–	–	1100	0.6	58.6	7.1
Turkey	0.042[a]	–	6.8[b]	–	9.2[a]	1.1
World total	170.8	–	185,000	–	826.0	–

Source: Refs. [1,23,26].
[a] Turkey's oil and coal reserve data adapted from Ref. [23].
[b] Natural gas reserve data adapted from Ref. [26]; the remainder of Table 5 adapted from Ref. [1].

the world [29]. They are on the verge of reaching their peak production. The fossil fuel resources are shortening day by day. With current consumption trends, the reserves-to-production ratio for coal stands at 122 years compared to 42 for oil and 60 for natural gas [1]. A current version of the estimates for fossil fuels is given in Table 3. Total coal reserves are very large, but oil and gas reserves are relatively much smaller.

Current energy supply in Turkey is primarily fossil-based fuels and these resources are shortening day by day, large power plants will need to be replaced over the next 30–40 years. The scarcity of known fossil reserves will make renewable energy sources more attractive [30].

3.3. The rapid rise in energy prices

Rapidly rising energy prices have become a major problem all over the world. The most important reason for rising prices is the growing imbalance between supply and demand in oil and other fossil fuels. Since 2003 energy prices have been rising rapidly, reaching a peak in 2007. Crude oil prices have more than tripled since mid-2003 and nearly doubled since 2004. Table 4 shows the development of fuel prices between 1985 and 2007.

Turkey's energy imports increased an average of 7% per year between 2003 and 2007, but its energy import bill increased an average of 31% per year, disproportionately large. The country's energy import bill increased sharply because of high fuel prices from US$11.6 billion in 2003 to US$33.9 billion in 2007. In 2007, its energy import bill accounted for almost one-fifth of the total import bill. It is known that Turkey, which has shown progress in such macro economic variables as GDP, export and import; is face to face with the problem of the current account deficit. In 2007, Turkey spent US$33.9 billion for the purchase of energy or almost 90% of current accounts deficit and more than 48% of foreign trade deficit. Key facts about the Turkish economy are presented in Table 5 [10,31–33].

Table 4
Development of fuel prices.

US$ per million btu	LNG Japan (CIF)	Natural gas European Union (CIF)	Crude oil OECD countries (CIF)
1985	5.23	3.83	4.75
1990	3.64	2.82	3.82
1995	3.46	2.37	2.96
2000	4.72	3.25	4.83
2001	4.64	4.15	4.08
2002	4.27	3.46	4.17
2003	4.77	4.40	4.89
2004	5.18	4.56	6.27
2005	6.05	5.95	8.74
2006	7.14	8.69	10.66
2007	7.73	8.93	11.95

Source: Ref. [1].

If the present trends continue, the country's dependency on imports to meet the energy demand will increase from 74% in 2007 to about 80% in 2030 [10]. It can be said that Turkey which is dependent in large measures on the outside for energy, will, because of increasing prices and procurement problems, come face to face with a very serious energy crisis in the future. This case clearly shows the great importance of adequately active and widespread use of domestic and renewable energy sources. Renewable energy sources require an energy investment before they generate a usable fuel. These up-front costs may be quite high, but on a life-cycle basis they are more and more affordable, for there are no fuel costs [34]. The number one reason for the slow investments in renewable energy technologies is the very high up-front capital costs.

3.4. The environmental problems

From GHG emissions point of view, Turkey is not that critical, since, as stated earlier, CO_2 emissions per capita are only three-

Table 5
Key facts about the Turkish economy.

	2003	2004	2005	2006	2007	Ref.
GDP (billion US$)	304.14	392.99	483.92	530.57	655.74	[31]
GDP growth rate (%)	30.5	29.2	23.1	9.6	23.6	[31]
Per capita income ($)	4532	5781	7028	7609	9305	[31]
Exports (billion US$)	47.25	63.17	73.48	85.5	107.27	[32]
Imports (billion US$)	69.34	95.54	116.77	139.58	170.06	[32]
Exports/imports (%)	82.7	78.0	73.0	71.4	73.2	[31]
Energy imports (billion US$)	11.6	14.4	21.3	28.6	33.9	[33]
Energy imports (mtoe)	60.0	63.5	66.5	71.2	78.5	[10]
Energy imports—net (% energy use)	72	72	73	73	74	[10]
Current account balance (billion US$)	−7.52	−14.43	−22.14	−31.89	−37.69	[31]
Foreign trade balance (billion US$)	−22.09	−34.37	−43.30	−54.04	−62.79	[32]
FDI—net (US$ billion)	1.75	2.78	10.03	20.18	22.21	[31]

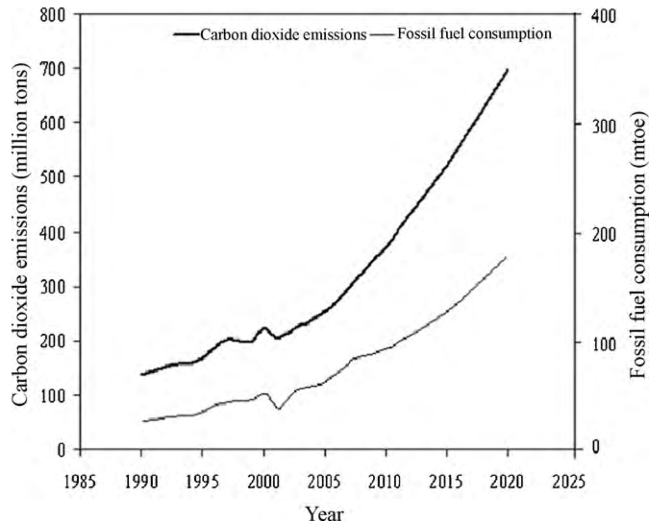


Fig. 4. Turkey's fossil fuel consumption and CO_2 emissions during the period 1990–2020.

Table 6
Year based increase of CO_2 emissions in Turkey.

Year	CO_2 emission (g*/KWh)
1990	527
1995	509
2000	580
2005	646
2010	656

Source: Ref. [38].
* g: gram = 10^{-3} kg.

quarters of world average. Although the demand of the country increases rapidly, Turkey's contribution to global GHG emissions is considerably below the average of Annex I countries [35]. Since 1990, CO_2 emissions in Turkey have grown two times as a result of its rapid economic growth, industrialization and urbanization. Total CO_2 emissions reach approximately 274 million tons in 2006 [32], with a 95% increase since 1990.

According to the 2006 data, CO_2 emissions occurred with the utilization of the fossil fuels to a great extent, while the rate of the fossil fuels within all CO_2 emissions was found to be 92.4% [36]. During the period 1990–2007, the share of fossil fuels in Turkey's primary energy consumption has increased from approximately 82% (42.9 Mtoe) [10] in 1990 to 91% (96.5 Mtoe) in 2007 [25]. On the other hand, fossil fuel consumption has increased by more than double during the same period. Fossil fuel consumption is projected to more than double again by 2020 [10], and CO_2 emissions will increase accordingly. Data on Turkey's fossil fuel consumption were collected from the MENR's energy statistics [10], CO_2 emissions data were collected from Turkey's Statistical Yearbook 2006 [36], Turkey's Statistical Yearbook 2008 [32] and a conference paper [37] for the period 1990–2020. Fig. 4 shows Turkey's fossil fuel consumption and CO_2 emissions from the 1990 to 2020.

During the period 2000–2006, CO_2 from the electric power sector have increased faster than the other sectors due to the rapid development of fossil fuel-fired power plants. Table 6 depicts the comparison of the weight size in grams of CO_2 emissions released into the atmosphere for each kWh of electricity use between 1990 and 2010 [38]. Fossil fuel-fired power plants are responsible for 33% of the country's total CO_2 emissions. Installed capacity of fossil fuel-fired power plants will rise from 27,272 megawatts (MW) in 2007 (approximately 67% of total capacity) [39] to 38,087 MW in 2010 and 69,190 MW in 2020 [40].

Sustainable development depends on a widespread use of clean and renewable energy. The environmental impact of renewable energy technologies is far less than that of fossil fuel-fired power plants. The Kyoto Protocol to the United Nations Framework Convention on Climate Change (UNFCCC), agreed to in December 1997, marks an important turning point in efforts to promote the use of renewable energy worldwide and the developed countries should decrease the net emission of CO_2 [41]. Among the types of renewable energy, wind has been the most popular and most approachable power source in recent years. The use of wind power as a renewable energy source is one of the means of achieving the GHG emission targets set in Kyoto agreement [42]. Life-cycle assessments of GHG emissions from wind turbines are very site-specific and sensitive to wind velocity conditions, because of the cubic relationship of wind velocity to power output. Since wind regimes vary significantly with geography different capacity factors used in the studies add to the variation that can be observed in the results, which lie between 8 and 30 grams of CO_2 equivalent per kilowatt hour (gCO_2eq/kWh) for onshore, and 9–19 gCO_2eq/kWh for off-shore turbines (Fig. 5) [43]. The 48,000 MW of wind power capacity installed in the European Union (EU) by the end of 2006 is already avoiding 108 million tons of CO_2 annually, or 20% of the EU's Kyoto obligation. Wind power in Europe will be meeting more than 30% of EU's Kyoto commitment to reduce CO_2 by 133 million tons by 2010 [44].

Transportation-related CO_2 emissions account for about 16% of Turkey's CO_2 emissions. According to European Environment Agency [45], by 2010, this sector will account for one-thirds of the country's CO_2 emissions. The use of biofuels can contribute to the mitigation of GHG emissions and provide a clean and therefore sustainable energy source [46]. Using biofuels in motor vehicles

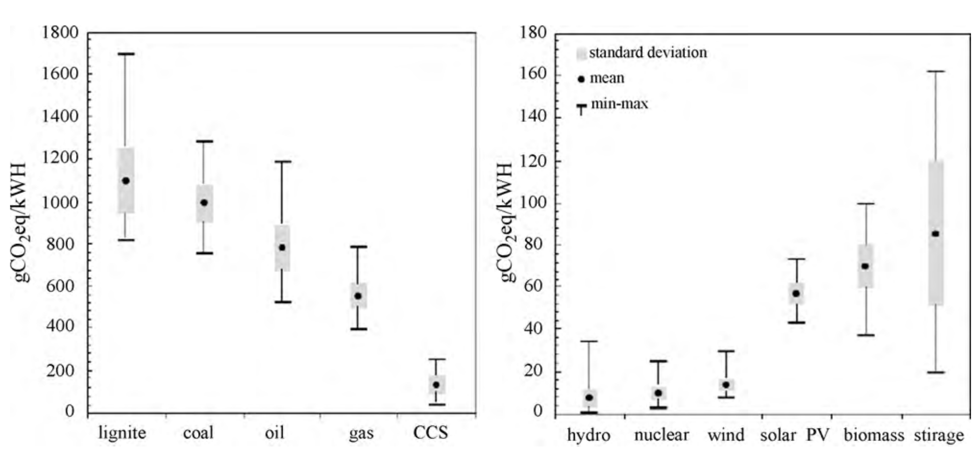


Fig. 5. Summary of life-cycle GHG emissions for selected power plants. Source: Ref. [43].

Table 7
Renewable energy resources in Turkey during the period 2000–2007 (thousand tons of oil equivalents).

	2000	2001	2002	2003	2004	2005	2006	2007
Total energy demand	77,624	71,609	75,465	79,402	81,999	85,340	94,663	101,510
Total energy production	26,808	25,161	24,648	23,873	24,212	23,626	26,540	27,279
Supply by RE[a]	10,149	9424	10,077	10,036	10,783	10,131	10,541	9604
Biomass and wastes	6546	6303	6039	5783	5550	5332	5162	5023
Wood/wood waste	6541	6297	6032	5775	5542	5325	5133	4994
Biogas	5	6	7	8	7	7	8	15
MSW[b]	–	–	–	–	–	–	–	–
Biofuels	0	0	0	0	0	0	21	14
Wind energy	3	5	4	5	5	5	11	31
Solar energy	262	287	318	350	375	385	402	420
Hydro energy	2655	2064	2896	3038	3963	3402	3804	3083
Geothermal energy	684	764	820	860	891	1007	1162	1048
Share (%)	13.07	13.16	13.35	12.64	13.15	11.87	11.14	9.46
Biomass and wastes (%)	8.43	8.80	8.00	7.28	6.77	6.25	5.45	4.95
Wood/wood waste (%)	8.42	8.79	7.99	7.27	6.76	6.24	5.42	4.93
Biogas (%)	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
MSW (%)	–	–	–	–	–	–	–	–
Biofuels (%)	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.01
Wind energy (%)	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.03
Solar energy (%)	0.34	0.40	0.42	0.44	0.46	0.45	0.42	0.41
Hydro energy (%)	3.42	2.88	3.84	3.83	4.83	3.99	4.02	3.04
Geothermal energy (%)	0.88	1.07	1.09	1.08	1.09	1.18	1.23	1.03

Source: Ref. [55].
[a] Renewable energy.
[b] Municipal solid waste.

helps reduce GHG emissions. Full-cycle analysis indicates that, on average, biofuels emit less CO_2 than conventional fuels [47,48]. CO_2 savings from biofuels are agreed at 50–70% better than gasoline and diesel and some 30% better than road fuel gases (which have a 40ppl rebate). Hence a blend of only 5% can deliver a 3% CO_2 saving [49]. Currently, under 2% of the EU's ever growing transport fuel needs are met by biofuels [50]. The EU has set a goal of 5.75% of transportation fuels use from biofuels by 2010 and 10% by 2020. However, Turkey has not set itself an ambitious target yet for biofuels use. In Turkey, biofuels are not supported by the public sector, but strongly pushed by private companies. Currently, there are regulations and strict rules in the field of biofuels [51]. Turkey's biodiesel production is expected to take off in coming years as the country aligns its regulations with those of the EU, including the EU directives relating to the encouragement of biofuels. Displacing 2% of Turkey's annual consumption of diesel fuel or around 35 million tons would require at least 700,000 tons a year of vegetable or animal oil [52].

The widespread use of renewable sources will not only development of a sustainable energy supply, but also will ensure the creation of new jobs. In addition, the use of renewable energy sources can have positive environmental impacts through the mitigation of climate change.

4. Present and future use of renewable energy in Turkey

In Turkey, the energy mix shows a relatively small contribution from renewable energy sources. However, Turkey is developing policies aimed at a more diversified mix increasing hydro, wind and geothermal electricity, solar and geothermal energy for heat and biofuels. Turkey has the biggest potential in Europe in terms of hydro [53], wind [54] and geothermal energy [12] and a very good potential in terms of biomass and solar energy. Despite an increase in the interest for renewable energy in the recent years, its share in the energy mix does not increase as energy demand has been growing steadily. The share of renewable energy in the energy mix has decreased from 13% in 2000 to 9.5% in 2007 [55]. Table 7 shows the renewable energy contribution in total energy demand during the period 2000–2007. According to MENR's 2020 projections [10], renewable energy sources will account for less than 9% of primary energy in 2020.

The share of illumination within the electricity consumption is increasing every year. Electricity demand in Turkey is growing rapidly, with the rate of increase at 8% on average for many years [56]. Turkey's electricity demand in 2008 was about 198 TWh [25] and is expected to increase to 242 TWh in 2010 and 499.5 TWh in 2020 [33]. This requires installed capacity to increase from about 42,000 MW in 2008 [39] to 65,000 MW by 2010 and 96,000 MW by 2020 [33]. This means that for the next 12 years, additional power generation plants must be established for an increased capacity of 54,000 MW. This requires a total investment of around US$84 billion until the year 2020. Investment requirement would be US$13 billion during the period 2007–2010, US$20 billion during the period 2011–2015 and US$51 billion during the period 2016–2020 [33].

Currently, electricity is mainly produced using thermal power plants (which consume coal, lignite, natural gas and fuel oil), wind energy, geothermal energy and hydropower plants in Turkey. Turkey's electricity production was about 198.2 TWh in 2008 [25], compared to 30.6 TWh in 1984 [39]. Until the 1980s, electricity production in Turkey was based on hydroelectricity, coal-fired and fuel oil power plants. Data on Turkish thermal and renewable-based electricity generation were collected from the Turkish Electricity Transmission Company's (TEIAS, Turkish acronym) 1984 electricity statistics [39] and the EUAS's 2008 Electricity Generation Sector Report [25]. Fig. 6 shows the observed data in 1984 and 2008. Coal-fired and fuel oil power plants together with hydroelectricity constitute almost all electricity production with the shares 33%, 23% and 44%, respectively; in 1984 (Fig. 6(A)). In 2008, their shares decreased to 29%, 5.2% and 16.7% [25] due to increasing use of natural gas for electric power generation. Today, gas-fired power stations produce nearly half of the electricity in Turkey (48.4% in 2008). The consumption of natural gas for power generation represents 55% of total gas consumption in 2008. In 2008, 82.6% of the Turkish electricity power generation was made by thermal power stations and 16.7% was made by hydroelectric

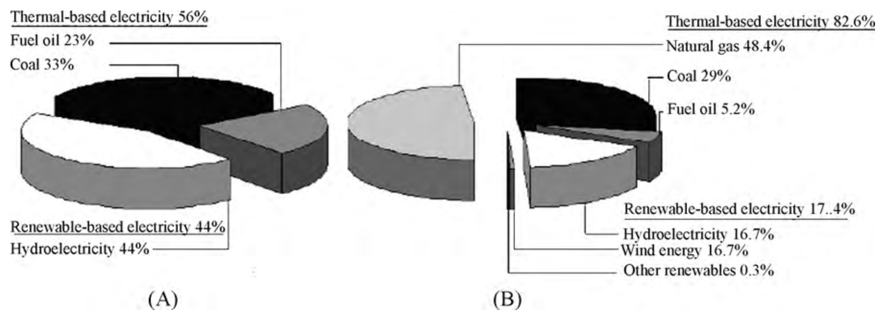


Fig. 6. (A) Thermal and renewable electricity generation in Turkey in 1984 and (B) thermal, and renewable electricity generation in Turkey in 2008.

power stations. The contribution of the stations based on wind and other renewable energy resources was 0.7% (Fig. 6(B)). Renewable energy sources were used to generate 34.5 TWh of electricity, which equates to 17.4% of all electricity produced.

The development and use of renewable energy sources are gaining ground in Turkey. In recent years, electricity generation from renewable energy sources has been promoted and encouraged and regulations concerning renewable energy sources have been established. The directive of the European Parliament with date of 27 September 2001 and number of 2001/77/EC endorses member countries to cover 12% of the first energy consumption from the renewable energy sources after the year 2010. The scarcity of renewable energy sources of EC will make the renewable electricity import from other countries as Turkey. Turkey may export renewable electricity to European countries by improving the renewable energy sources and by developing the electricity interconnection [57].

4.1. Wind energy

According to a study [58], Turkey has one of the richest wind energy potentials among European countries, can even meet all of the electricity needs from wind energy. Turkey's total theoretically available potential for wind power is estimated to be around 88,000 MW. Turkey's total economically feasible potential for wind power is estimated at some 10,000 MW [59–62]. As for Turkey's situation related to wind energy utilization, it can be seen that Turkey is rather unsuccessful in using its potentials and has only 12 wind power plants with installed capacity [63].

Turkey's installed wind capacity tripled during 2007 from 50 MW to almost 150 MW and again in 2008 to 433 MW [64]. A further 402 MW are under construction and 668 MW have secured supply contracts for wind turbines [65]. The installed capacity of wind energy is expected to reach from 433 MW in 2008 [64] to 11,200 MW by 2025 [40], where the share of wind energy for generating electricity would increase from 0.4% [25] to 3.6% [13]. The Energy Market Regulatory Authority (EMRA) has stated that 751 license applications (totaling 77,871 MW) for wind electricity generation projects. The distribution of the applications is mentioned below [66]:

- 24% Aegean Region (Izmir 114, Manisa 23, Aydin 18, Mugla 15, Denizli 5),
- 49% Marmara Region (Istanbul 47, Edirne 15, Kirklareli 44, Tekirdag 18, Çanakkale 93, Kocaeli 11, Yalova 7, Sakarya 10, Bilecik 3, Bursa 26, Balikesir 87),
- 16% Mediterranean Region (Hatay 63, Mersin 32, Karaman 14, Osmaniye 5),
- 8% Black Sea Region (Ordu 7, Kastamonu 7, Sinop 6, Amasya 5, Tokat 4), and
- 3% other regions.

Until today, EMRA has given license to 58 wind energy power plants, which have a total capacity of 2,126 MW. In July 2008, it has been decided to give license to 13 wind power plant projects, which will annually generate approximately 2 TWh of electrical energy [67].

Up to now, Turkey has not been a significant wind turbine manufacturer. Enercon has a production line in Izmir and has been producing 0.8 MW turbines since 2005. Manufacturers that sold most wind turbines in Turkey (2009-contracted) [68]:

- Enercon (Germany) with 36% market share,
- Vestas (Denmark) with 24% market share,
- GE Wind (USA) with 20% market share,
- Nordex (Germany) with 16% market share, and
- Suzlon (India) with 4% market share.

Enercon and Vestas seem to be dominating most of the contracts in the Turkish market, but new Turkish players are making their way into the market. Soyut Enerji produces small-scale turbines, whereas Model Enerji is going to be the first MW-level turbine manufacturer in Turkey [68]. The private sector plans to invest 2000–3000 MW wind power projects over the next 3–5 years in Turkey [69].

4.2. Hydro

Hydropower is by far the most important form of renewable electricity produced in Turkey [70]. The political desire to exploit more of the estimated 433 TWh of theoretical hydropower potential has been strengthened by volatile gas prices and intermittent service from its two main suppliers, Russia and Iran [71]. Almost half of the gross potential is technically exploitable, and 28% is economically exploitable [72,73].

Turkey has 172 hydroelectric power plants [74] in operation with total installed capacity of 13,830 MW [39] generating an average of 33.1 TWh/year [25], which is 39% of the economically feasible hydro potential. In 2008, the share of hydroelectric was about 16.7% of total electricity production of the country (Fig. 6(B)). It represented approximately 96% of electricity production from renewable energy sources in 2008. During the period 2000–2008, the hydroelectric installed capacity increased from 11,175 MW to 13,830 MW [39]. According to the governmental plan, the hydroelectric installed capacity will reach 35,000 MW in 2020, accounting for 36.5% of the total installed capacity.

Turkey is developing a great deal more hydroelectric power plants, especially as part of the US$32 billion Southeastern Anatolia Project (GAP, Turkish acronym) along the basin of the Tigris and Euphrates rivers [75]. These projects envisage the construction of 22 dams and 19 power plants, generation of 27 TWh of energy a year over an installed capacity of 7.5 GW [13].

Furthermore, small hydropower has a huge, as yet largely untapped potential in Turkey and can make a significant contribution to future energy needs. The gross theoretical small hydropower potential of Turkey is 50 TWh/year. The technically and economically feasible potential is 30 and 20 TWh/year, respectively. Only 3.3% of economically feasible potential is developed so far [76].

4.3. Solar energy

Turkey has also considerable solar energy potential. Three-fourths of the economically usable potential is considered suitable for thermal use, with the reminder for electricity generation [77]. Currently, Turkey does not have an organized commercial and domestic photovoltaic (PV) program [73,78]. On the other hand, there is good potential for PV applications in the local market since the country is enormously suitable due to high rates of solar radiation and available land for PV applications [79]. The PV generation application is insignificant and currently, the total PV generation capacity in Turkey is 3 MWp [80]. PV energy is used for signalling purposes and in rural areas such as the watch towers of the Ministry of Environment and Forestry, light houses and lighting of highways [80]. Monthly solar energy potential of Turkey is given in Table 8 [81].

With an installed solar thermal capacity of 7.1 GWt, Turkey is currently the third largest producer of solar thermal power worldwide, after China (84 GWt) and the EU (15.5 GWt) [82]. The annual average total insolation duration is 2640 h (7.2 h/day), while the average annual solar radiation is 1311 kW h/m^2/year (3.6 kW h/m^2/day) in Turkey [83]. Solar collectors mounted in 2007 were 18 million square meters [84], and total energy production related to this amount was 420 thousand toe [10].

4.4. Geothermal energy

Turkey has significant potential for geothermal power production, possessing one-eighth of the world's total geothermal potential [85–87]. The overall geothermal potential in Turkey is about 38,000 MW (electric and thermal) [13]. Much of this potential is of relatively low enthalpy that is not suitable for electricity production but is still useful for direct heating applications [88].

Turkey is ranked as fifth biggest geothermal energy user for heating and hot spring purposes after China, Japan, USA and Island [61,79]. Turkey has increased their installed capacity over the past 10 years from 140 MWt to 1177 MWt, which now supplies heat equivalent to the needs of 70,000 homes [89]. By 2020 capacity will have grown to 8300 MWt for space heating and 1000 MWe for electricity [90].

The share of geothermal energy in Turkey's energy mix was only 1% in 2007 (Table 7). Its use is expected to reach 6.3 Mtoe by 2020 [57,91,92], accounting for approximately 3% of the national energy mix.

Table 8
Monthly average solar potential of Turkey.

Months	Monthly total solar energy (Kcal/cm^2-month)	Monthly total solar energy (kWh/m^2-month)	Sunshine duration
January	4.45	51.75	103.0
February	5.44	63.27	115.0
March	8.31	96.65	165.0
April	10.51	122.23	197.0
May	13.23	153.86	273.0
June	14.51	168.75	325.0
July	15.08	175.38	365.0
August	13.62	158.40	343.0
September	10.60	123.28	280.0
October	7.73	89.90	214.0
November	5.23	60.82	157.0
December	4.03	46.87	103.0
Total	112.74	1311	2640

Source: Ref. [81].

4.5. Biomass energy

Biomass is the major source of energy in rural Turkey. The amount of annual biomass potential of Turkey is approximately 32 Mtoe. The total recoverable bioenergy potential is estimated to be about 17 Mtoe [13]. Among OECD countries, Turkey takes the fourth place from the top in the estimated total energy potential from crop residues with 9.5 Mtoe [18]. Biogas production potential in Turkey has been estimated at 1.5–2 Mtoe but only two small units (in total 5 MW) are in operation and one new facility (1 MW) has been licensed [20,93]. Around 85% of the total biogas potential is from dung gas, and the remainder is from landfill gas. The dung gas potential is obtained from 50% sheep, 43% cattle and 7% poultry [20,94,95].

5. Present policy and legal aspects of renewable energy in Turkey

Turkish government has not yet set a target for electricity generation from renewable energy sources but utilization of renewable energy sources as an alternative to fossil fuels in the country has been promoted and encouraged particularly over the past decade. Positive achievements have been obtained in renewable energy development and manufacturing. The renewable energy-related legislation has noticeably been intensified. A series of rules and regulations, such as the "Law on Electricity Market", "Law on Renewable Energy" and "Law on Geothermal Resources and Natural Mineral Waters" have been stipulated in succession.

The Electricity Market Law (EML, No. 4628), which was enacted in February 2001, authorizes the EMRA to take the necessary measures to promote the utilization of renewable energy sources. In the scope of the EML, the generation of electricity from renewable energy sources is encouraged. The EML contains two regulations concerning the promotion of the use of renewable energy sources. The legal entities applying for licenses for the construction of facilities based on renewable energy sources shall pay only 1% of the total licensing fee. Also renewables based generation facilities shall not pay annual license fees for the first 8 years following the facility completion date inserted in their respective licenses.

In the following years activity related with the issuing of licenses by the Authority was accompanied by the termination of some of them under reasons stipulated in the EML and secondary legislation. The latest statistical data, as of April 2007, about valid licenses held by private companies for generation, by auto-producers and auto-producer groups, as well by EUAS and its affiliates is given in Table 9 [96].

The EML was amended by Law no. 5784 on 9 July 2008 (New EML). According to the new EML, production of electricity from renewable energy up to a capacity of 500 kW is exempt from the need to obtain a production license.

In May 2005, the government passed the Renewable Energy Law No. 5346, which aims to expand the use of renewable energy sources for producing electricity in a dependable and economic manner, to increase the diversification of energy sources, to reduce GHG emissions, to assess waste products, to protect the environment and develop the related manufacturing sector to realize these objectives. "The electricity generation resources suitable for wind, solar, geothermal, biomass, biogas, wave, current and tidal energy

Table 9
Electricity generation licenses, as of April 2007.

	HPP[a]		TPP[b]		RPP[c]		Total	
	Number	Capacity (MW)	Number	Capacity (MW)	Number	Capacity (MW)	Number	Capacity (MW)
PS[d]	184	5065.4	61	5979.8	43	1284.5	288	12329.6
EUAS[e]	108	11446.1	1	15.0	17	8992.4	126	20453.5
AAG[f]	4	548.2	191	3107.3	5	9.6	200	3665.3
Total	296	17050.7	253	9102.1	65	10286.5	614	33149.4

Source: Ref. [96].
[a] HPP—hydro power plants.
[b] TPP—thermal power plants.
[c] RPP—power plants on renewable resources.
[d] PS—private sector.
[e] EUAS—Turkish Electricity Generation Company.
[f] AAG—auto-producers and auto-producer groups.

resources together with hydraulic generation plants either canal or run of river type or with a reservoir area of less than fifteen square kilometers" are defined renewable energy resources to be supported in the scope of this law. Specific incentives provided by the law are as follows:

- Each legal entity holding a retail sale license shall be entitled to purchase renewable energy source-certified (RES-certified) electrical energy in an amount declared by EPDK. According to this law retail electricity licensees have to purchase at least 8% of their annual electricity sales volume from renewable energy sources.
- Until the end of 2011, the applicable price shall be the average wholesale electricity price of the previous year determined by the EMRA, though the Council of Ministers is entitled to raise this price up to 20% at the beginning of each year. The price to be applied cannot be less than the Turkish Lira equivalent of 0.05 €/kWh and more than the Turkish Lira equivalent of 0.055 €/kWh.
- After 2011, this pricing methodology shall not be applicable for the RES-certified power plants that are in operation for more than 7 years. No plant shall benefit from the compulsory purchase provisions for more than 7 years.
- The law provides certain incentives concerning the investment periods of energy projects. For example, investments for energy generation facilities, procurement of electro-mechanic systems within Turkey, research, development and production investments regarding solar energy units, and research and development investments for biomass energy may benefit from the incentives determined by the Council of Ministers.
- The need for heat energy in the municipalities and governorates with sufficient geothermal energy resources shall be met primarily by geothermal and solar thermal energy resources.

Currently there are amendments being made to the Renewable Energy Law. The Draft Law for renewable energy sources includes a feed-in tariff for photovoltaics of 0.25 €/kWh only for the first 10 years of operation, dropping to 0.20 €/kWh for the next 10 years.

The Geothermal Resources and Natural Mineral Water Law No. 5686 dated 13 June 2007 was put into effect which aims to explore, analyze, develop, produce, preserve and put to economical and environmentally friendly use the geothermal and natural mineral waters. A special license is required to carry out exploration activities. The license may be issued according to the procedure regulated by these provisions and shall be valid for a maximum period of 3 years. An operational license is also necessary to exploit geothermal resources. Operational licenses are valid for 30 years and may be extended for up to 10 years.

Since 2005, the rate of geothermal fields exploration and research activities of the General Directorate of Mineral Research and Exploration (MTA, Turkish acronym) have increased by multiple times. The number of geothermal fields discovered by MTA increased from 170 in 2005 to 187 in 2008. Five of the newly discovered geothermal sites are suitable for electricity production [97]. These five fields are: Aydın-Umurlu (423 K), Aydın-Sultanhisar (419 K), Aydın-Bozköy (416 K), Aydın-Atça (397 K) and Aydın-Pamukören (461 K).

6. Renewable energy outside of Turkey—are there lessons to be learned?

Renewable energy sources (including hydro) supply approximately 13% of global primary energy demand (Table 1) and 18.2% of global electricity generation [98]. Data on electric power production were collected from Observ'ER [98]. Fig. 7 shows the observed data for 2007. Hydroelectric power is a very significant source and its contribution to global production of electricity in 2007 was 15.9% (Fig. 7 (A)). Hydroelectric power accounts for about 87.3% of renewable electricity production (Fig. 7 (B)). Renewable energies could provide approximately half of the global energy demand by 2040, according to European Renewable Energy

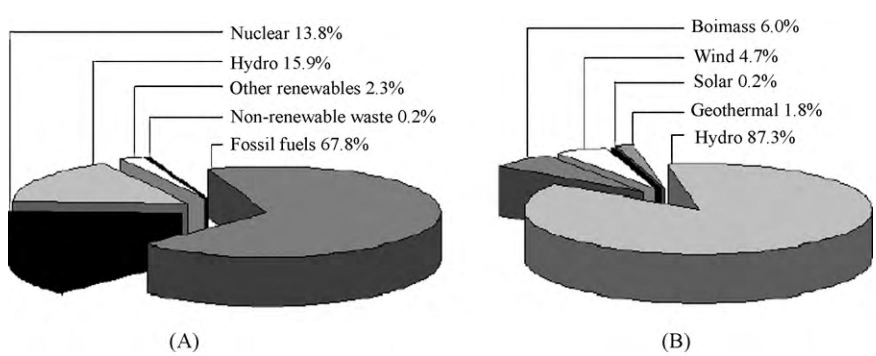


Fig. 7. (A) The global electricity generation mix in 2007 and (B) the global renewable-based electricity generation mix in 2007.

Council [99]. PV systems and wind energy will be able to play an important role in the energy scenarios of the future [100].

Global investment in renewable energy set a new record of $120 billion in 2008, according to the Renewable Energy Policy Network [82]. In the period 2004–2008, there was a 76% increase in renewable electricity generation capacity worldwide (excluding large hydro)—from 160 GW [101] to 282 GW [82]. At the end of 2008, the top six countries in terms of installed capacity were China (76 GW), the United States (40 GW), Germany (34 GW), Spain (22 GW), India (13 GW), and Japan (8 GW) [82]. In 2007, the electricity production from renewable sources was 3,604 TWh [98] with a large contribution of electricity produced from hydro plants to the total (87.3% in 2007). The top 10 countries in terms of electricity production from renewable sources (including hydro) were China (471 TWh), Brazil (392 TWh), the United States (387 TWh), Canada (382 TWh), Russia (190 TWh), Norway (137 TWh), India (137 TWh), Japan (110 TWh), Germany (97 TWh), and Venezuela (81 TWh) [98]. These ten countries accounted for 66.1% of world renewable-based electricity production. China is world's largest producer of renewable electricity (including large hydro), with 13% of total production, followed by Brazil (10.9%), the United States (10.7%), and Canada (10.6%). However, renewables constitute less than 15% of total electricity production in China, while they provide 88% of the total production in Brazil. Table 10 provides a comparison of Turkey with selected countries in terms of their renewable electricity generation. Compared with renewable electricity generation of selected countries, Turkey takes place for beyond the list at the last level.

Wind energy is now the world's fastest growing renewable energy source. Today, wind energy is mainly used to produce electricity. According to the Observ'ER [98], it has increased worldwide at an annual rate exceeding 29.6% since 1997. The worldwide cumulative wind installed capacity reached 122 GW in 2008 [102], up from 59 GW in 2005 [103] and 7.6 GW in 1997 [104]. Fig. 8 shows the worldwide cumulative wind installed capacity during the period 1997–2008. By the end of 2008, the United States led the world with installed capacity of 25,170 MW [82], or one-fifth of the global total. Germany is second with 23,900 MW, Spain is third with 16,740 MW, and China is fourth with more than 12,200 MW [82]. In 2013, cumulative wind installed capacity in the world will have reached 343 GW, of which 145 GW will be in the EU according to BTM Consult ApS [105]. Wiser and Bolinger [106] reported that the United States wind power additions increased by 60% in 2008 with $16 billion in new investment. That raised to nearly $45 billion the total wind power investment in the United States since the 1980s [107]. Wind energy in the United States can grow from installed capacity of 25.2 GW [82] supplying 2% of its electricity in early 2009 [107], to a total of 305 GW of capacity by 2030 [108]. These wind farms could provide 20% of the nation's electricity needs by 2030, according to Hand et al. [108]. Wind power is also a job creation dynamo, creating 35,000 jobs in 2008 alone despite the economic downturn and providing a broad range of business and employment opportunities in different regions of the United States [109]. Today, 85,000 jobs have been created in the country's wind energy industry [109].

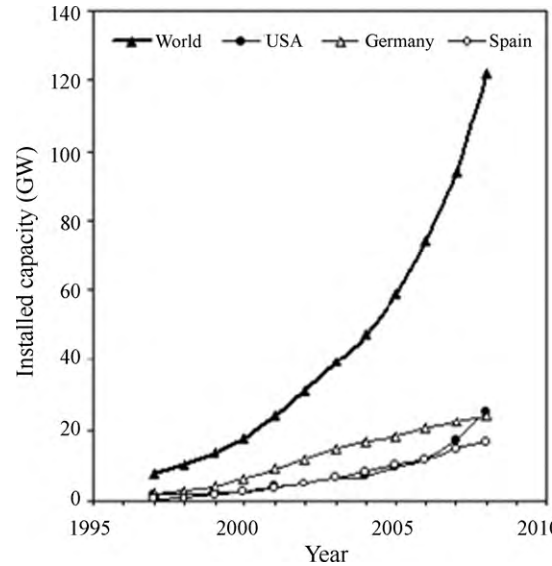


Fig. 8. The worldwide cumulative wind installed capacity during the period 1997–2008.

The solar PV industry has rapidly become one of the world's fastest growing industries.

Solarbuzz [110] reported that world PV cell production reached a consolidated figure of 6.85 GW in 2008, up from 3.44 GW a year earlier. Grid-connected solar PV capacity grew by 70% in 2008 to reach 13 GW, as reported by Renewable Energy Policy Network for the 21st Century [82]. Cumulative PV power installed worldwide jumped from 10.5 GW in 2007 [111] to almost 16 GW in 2008 [82].

Table 10
A comparison of Turkey with selected countries in terms of their renewable electricity generation[a].

Country	TEG[b] (TWh)	REG[c] (TWh) (Incl. hydro)	SRE[d] (%) (Incl. hydro)	REG[c] (TWh) (Excl. hydro)	SRE[d] (%) (Excl. hydro)
Turkey[e] (a)	198.2	34.4	17.4	1.3	0.66
Selected countries[f] (b)					
China	3246.7	471.2	14.5	9.3	0.29
Brazil	446.1	392.2	87.9	17.8	3.99
USA	4376.5	386.7	8.8	108.9	2.49
Canada	637.2	381.4	59.9	12.3	1.93
Russia	1011.0	189.6	18.8	0.4	0.04
India	801.5	136.7	17.1	14.7	1.83
Norway	138.3	136.6	98.8	1.3	0.94
Japan	1139.2	110.3	9.7	24.7	2.17
Germany	641.1	96.6	15.1	69.1	10.78
Venezuela	110.6	80.6	72.9	0	0

[a] The lower-case letters in parentheses represent the different authors from which renewable electricity generation were sourced from literatures for this work: (a) Ref. [25] and (b) Ref. [98].
[b] TEG-Total electricity generation.
[c] REG- Renewable electricity generation.
[d] SRE- Share of renewables in total electricity.
[e] 2008 data.
[f] 2007 data.

Since 2004, Europe has been leading the global market for PV applications. In 2008, Europe represented over 80% of the global PV market [112]. The top three PV-producing countries are China (1.8 GW), Germany (1.3 GW), and Japan (1.2 GW) [113]. In terms of installations Spain has been the leading market for PV installations since it overtook Germany in 2006. In 2008, Spain, adding 2,460 MW [110], became the first country to install more than 2 GW in a single year. This growth is explained by the reduction in solar PV energy feed-in tariff from the end of September 2008, which prompted a rush for installations. Prior to the rate change, the tariff was 44.04 €cent/kWh for installations up to 100 kW for 25 years, 41.75 €cent/kWh for plants delivering 100 kW to 10 MW and 22.94 €cent/kWh for plants delivering up to 50 MW [114]. As a consequence of the surge in Spain, the PV industry generated $37.1 billion in revenue globally, up from $17.2 billion the previous year, according to Solarbuzz [110]. Germany followed in second place, with new installations of about 1500 MW [115]. The top five also including the United States (342 MW), South Korea (274 MW), and Italy (260 MW) [112]. The cumulative solar PV installed capacity in the United States was 1,111 MW in 2008 and it is aimed to reach 5293 MW in 2013, according to a recent report by GlobalData [116].

Existing solar hot water and heating capacity grew by 15% in 2008 to reach an estimated 145 GW [82]. China is a world leader in solar thermal production and use, accounting for two-thirds (79.9 GW) of total global capacity in 2007 [117]. There are over 1000 enterprises and the employees are over 150,000 [118]. The issues associated with the integration of solar water heaters into buildings have already attracted strong attention from relevant national-level and local government departments, architects and real estate developers, and solar water heater integrated building is the developing trend in this field [118,119]. Chinese government aims to more than double the current 124 million square meters of rooftop solar water heaters to 300 million square meters by 2020 [120].

EU has moved aggressively to promote renewable energy in a number of countries. The share of energy generated from renewable energy sources for the EU is targeted to increase from the current 8.5% to 20% by 2020 [121]. The Chinese government set a goal in 2007 for the country's renewable energy to account for 1.8 GW of solar power capacity, 300 GW of hydropower, 30 GW of wind power and 30 GW of biomass power by 2020 [122]. China currently gets 7.5% of its primary energy from renewable energy sources [123]. The government aims to expand that to 15% by 2020 [123]. According to a study [124], Brazil supplies 60% of its primary energy requirements from renewable energy sources, most of which comes from hydropower and biomass. Brazil's energy plan sought to slightly increase through 2030 its existing share of primary energy from renewables and its electricity share [82].

7. Conclusion

Current energy supply in Turkey is primarily fossil-based fuels and, although these resources are shortening day by day, large power plants will need to be replaced over the next 30–40 years. Renewable energy sources are currently small fractions of the country's energy supply. Turkey has the biggest potential in Europe in terms of hydro, wind and geothermal energy and a very good potential in terms of biomass and solar energy. Despite an increase in the interest for renewable energy in the recent years, its share in the energy mix does not increase as energy demand has been growing steadily. The share of renewable energy in the energy mix has decreased from 18% in 1990 to 9.5% in 2007.

Renewable energy should be taken as a key way to reduce the country's heavy dependence on imported energy and must be put in the first position. Turkey should encourage the adoption of renewable energy to meet its growing energy needs. This will not only reduce its dependence on imports of fuel to produce energy, but will also ensure a continued local source of energy, development of a sustainable energy supply, and the creation of new jobs. In addition, widespread adoption of renewable energy sources will benefit from economic markets that place a true cost of using fossil fuels (such as environmental damage or cleanup required) on the user and not on society as a whole.

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